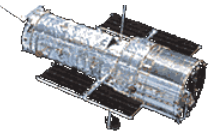


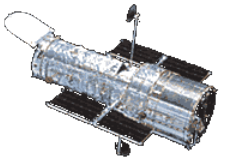
HST Replacement Battery Initial Performance

Stan Krol, Greg Waldo

Lockheed Martin Information Systems & Global Services

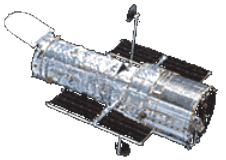
Roger Hollandsworth

Lockheed Martin Space Systems Company



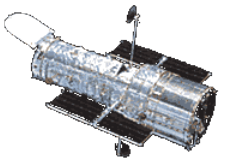
Introduction

- The Purpose Of This Presentation Is To Highlight The Findings From The Assessment Of The Initial SM4 Replacement Battery Performance
- The Assessment Period Starts At SM4 Release On May 18, 2009 And Covers Through November 8, 2009.
- The Assessment Examines The Battery Voltage, Current, Thermal, Pressure, State Of Charge And Impedance Performance.



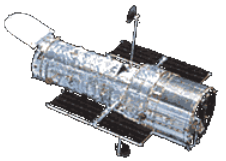
SM4 Battery Replacement

- **The HST original Nickel-Hydrogen (NiH2) batteries were replaced during the Servicing Mission 4 (SM4) after 19 years and one month on orbit.**
- **The replacement batteries were installed during EVA2 (Bay 2) and EVA5 (Bay 3).**
  - Bay 2 contains battery (SN): 1 (1161), 2 (1162) and 3 (1163)
  - Bay 3 contains battery (SN): 4 (1166), 5 (1165) and 6 (1164).
- **Aliveness Tests and Functional Test were executed successfully with no liens**

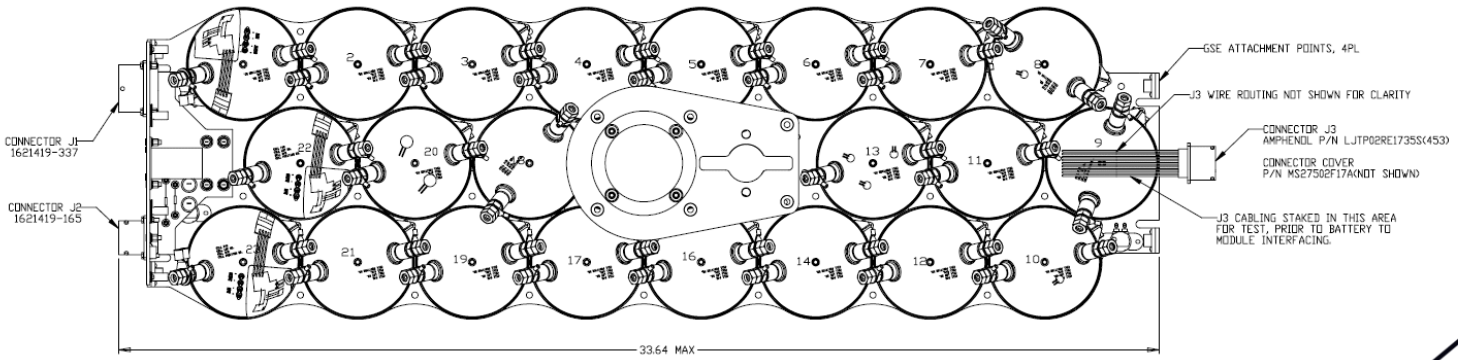


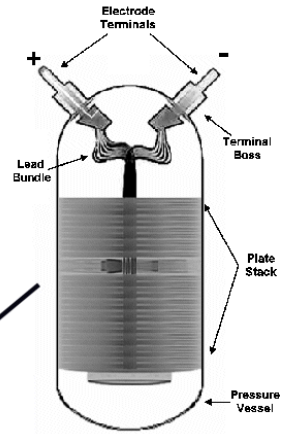
Battery Description

- **22 Electrically Series Connected RNH 90-3 NiH_2 Cells**
- **Wet Slurry Nickel Positive Electrodes & Double Layer Zircar Separator**
  - Nickel Precharge
  - 1990 Original: Dry Sinter – Hydrogen Precharge
- **Battery Isolation Switch (BIS) (EVA Operated Only)**
- **Current Sensor**
- **Individual Cell Heaters**
  - 2 Independent Heater Circuits, Primary And Redundant
- **2 Independent Strain Gauge Pressure Monitoring Circuits**
- **Temperature Monitoring Circuit (Telemetered)**
- **4 Charge Control Thermistors (Not Telemetered)**
- **Individual Cell Voltage Monitoring Test Connector J3 (GSE Only)**

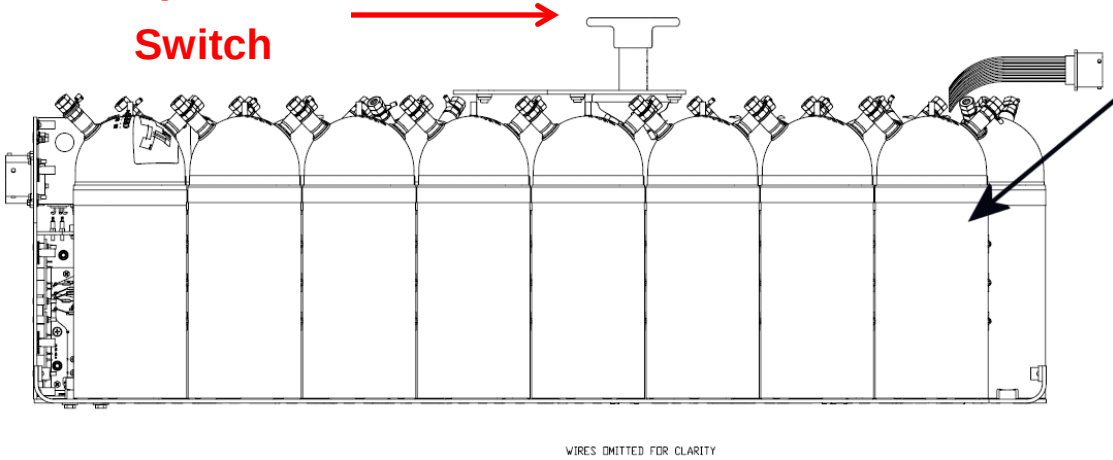


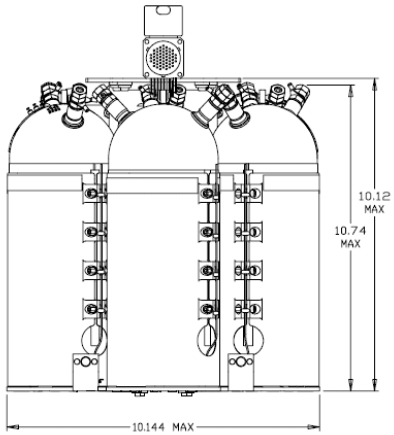
Battery Description (continued)





Battery Isolation Switch

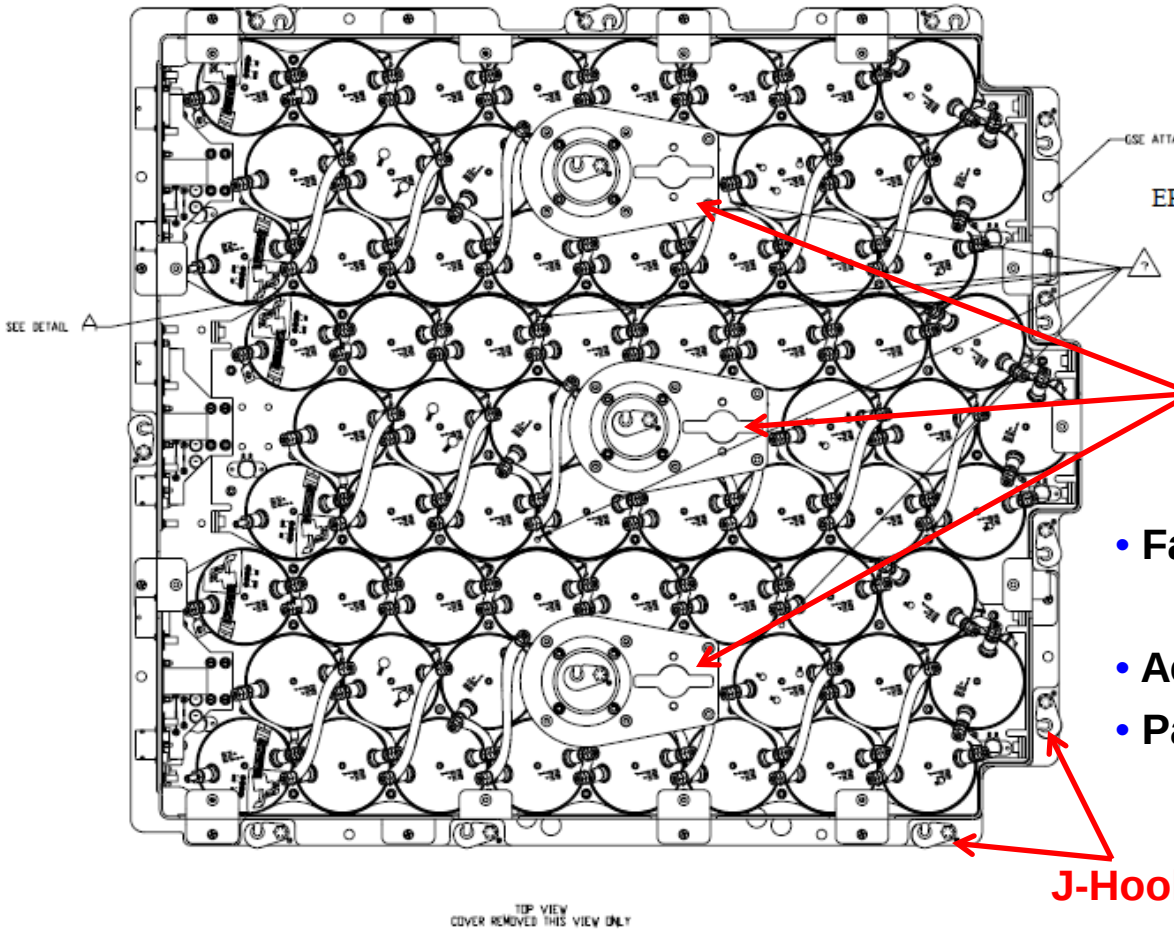




Nameplate capacity: 88AH

Battery Description

- **The Six Batteries Are Housed Within Two Modules (S/N 1032 & 1033). Each Module Consists Of 3 Electrically Independent Ni-h2 Batteries Mounted To A Battery Module Base Plate.**



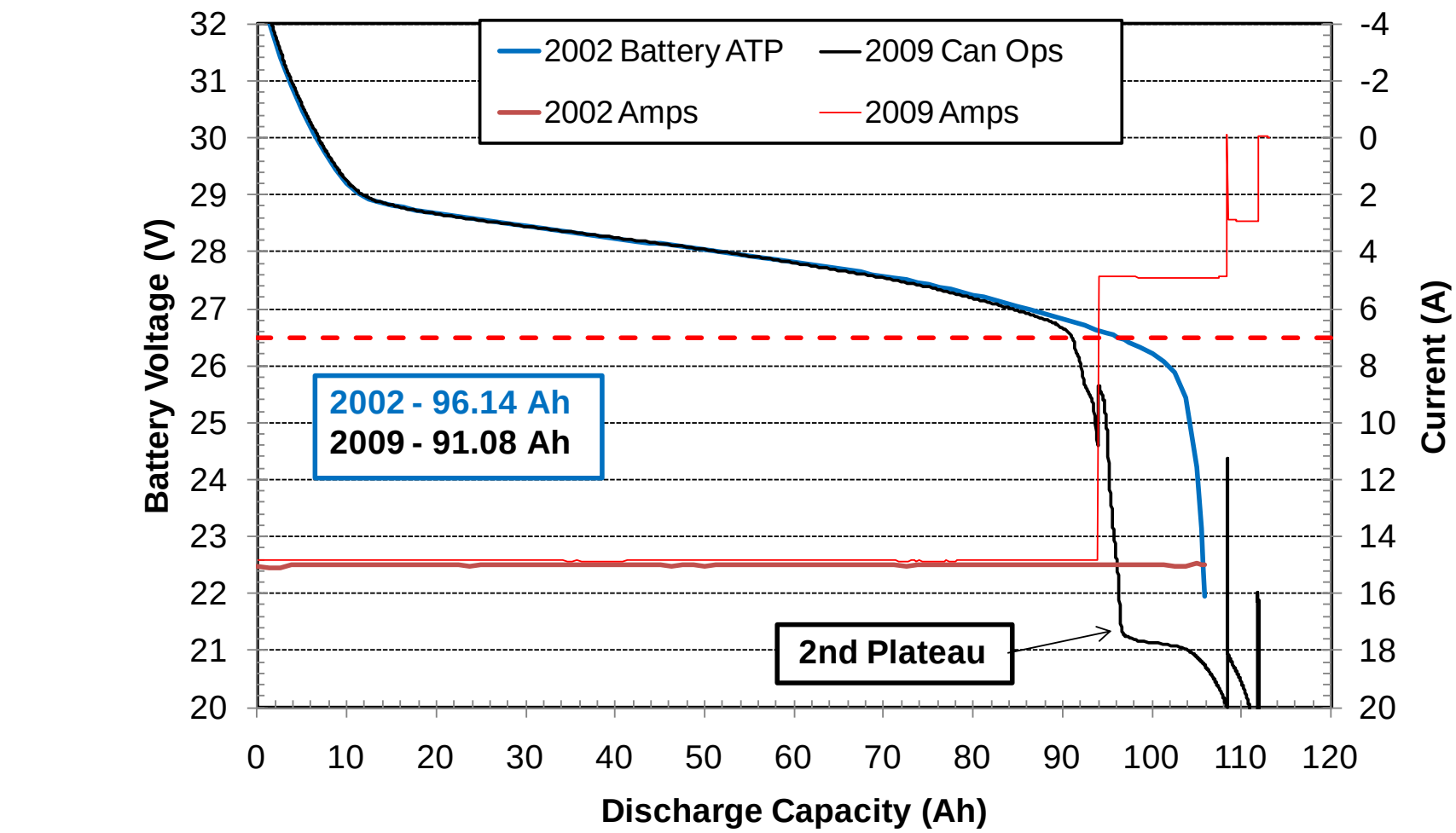
- Size: 36” H x 32” W x 15” H
- Weight: 475 lbs each module

Battery Isolation Switch

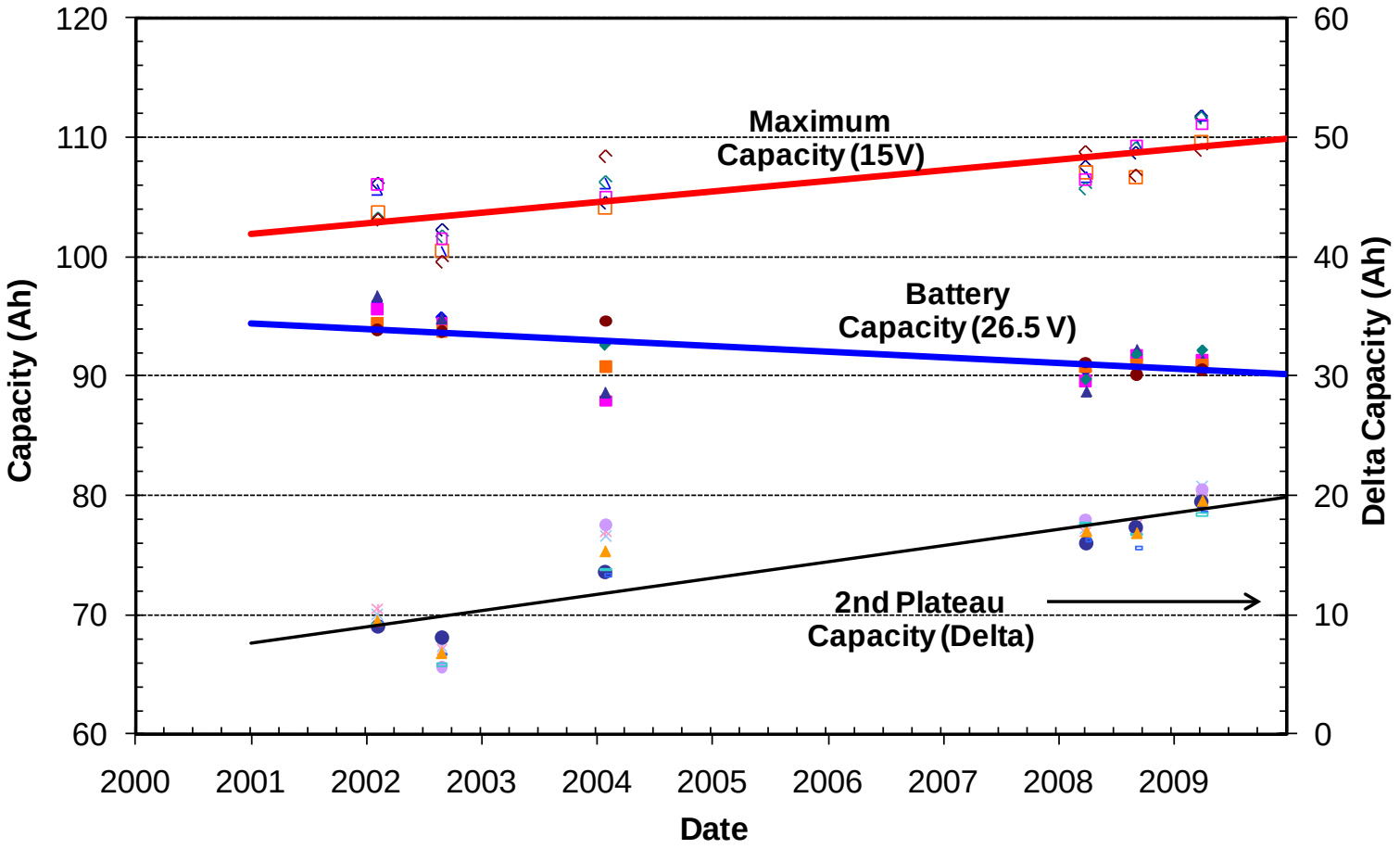
- **Fabrication**: January 1995-96
  - **Dry Stored for 4 Years**
- **Activatation**: September 2000
- **Passively Stored** Until April 2009
  - **Wet Stored 9 Years**

J-Hook – Attach to Bay Door

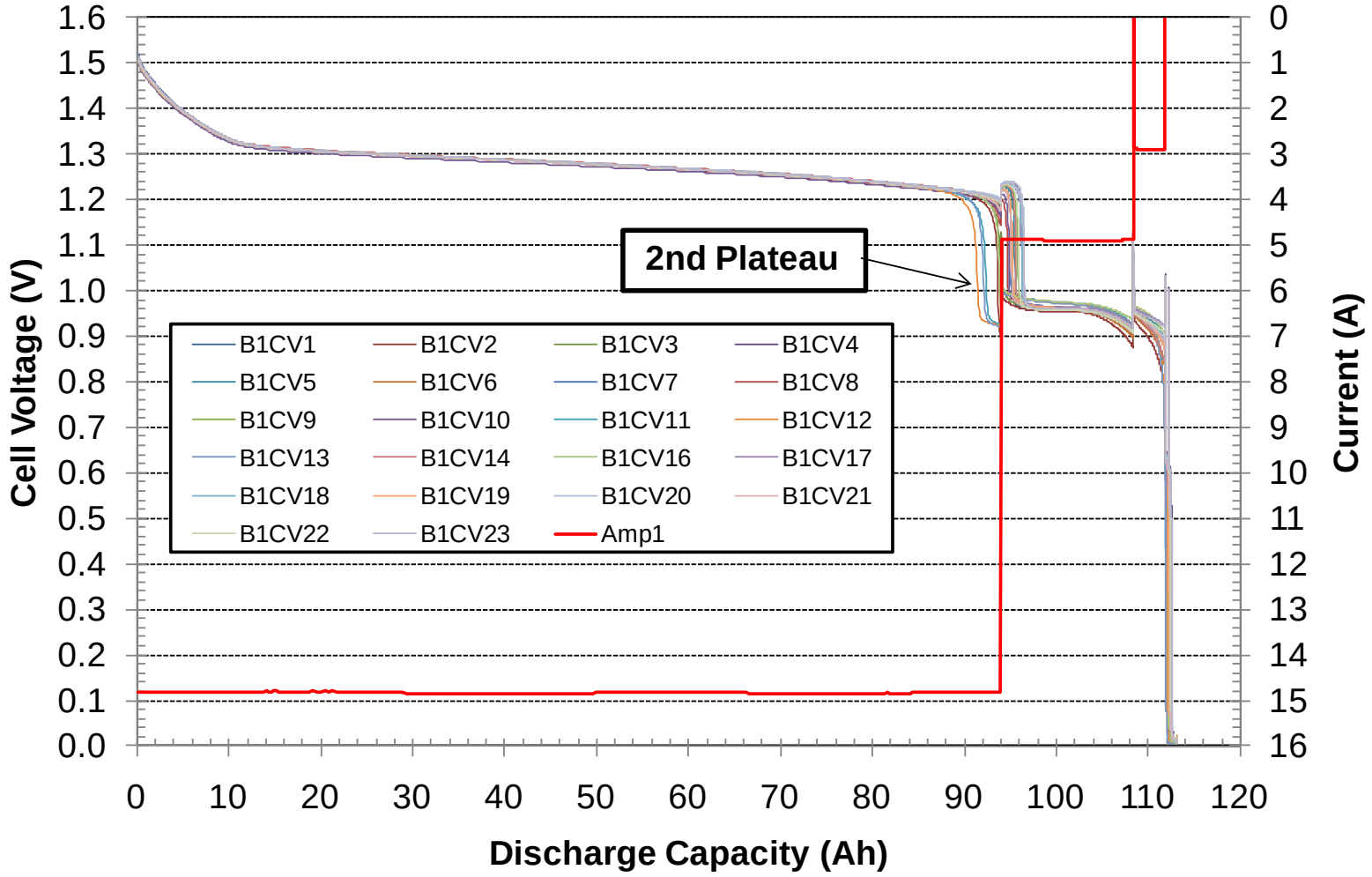
Battery 0°C Capacity

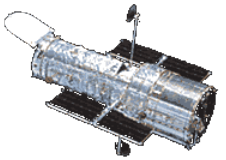


Battery 0°C Capacity Trend



Battery 0°C Cell Capacity





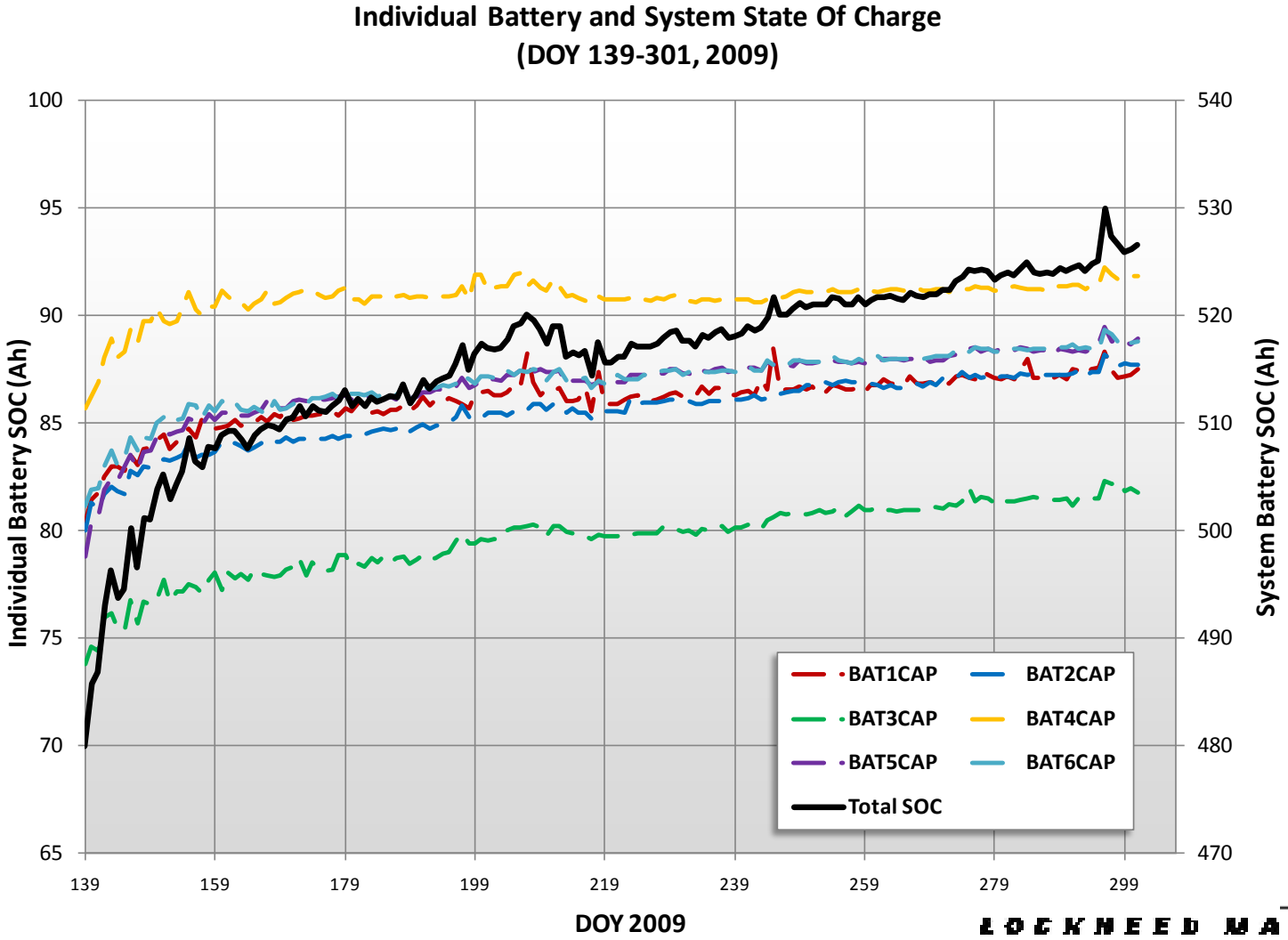
State Of Charge (SOC) Performance

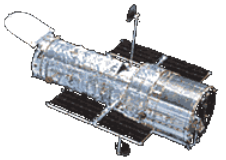
- **The Table Below Shows The Battery Pressure Based SOC's At The Time Of Installation, Release And Release +30 Days (DOY 169 / 09) and present (DOY 301/09)**

Battery	Install SOC (Ah)	Release Full SOC (Ah)	DOY 169/09 Full SOC (Ah)	DOY 301/09 Full SOC (Ah)
1	52.3	67.7	86.2	87.5
2	53.3	66.8	84.9	87.8
3	49.0	62.3	80.4	82.1
4	58.0	73.4	92.2	92.0
5	52.5	66.9	86.4	89.0
6	56.9	67.9	90.4	88.8

State Of Charge (SOC) Performance

- At The Time Of HST Release, The Battery SOC Was 484 Ah
- SOC Continues To Increase And As Of DOY270 Is Above 525 Ah.



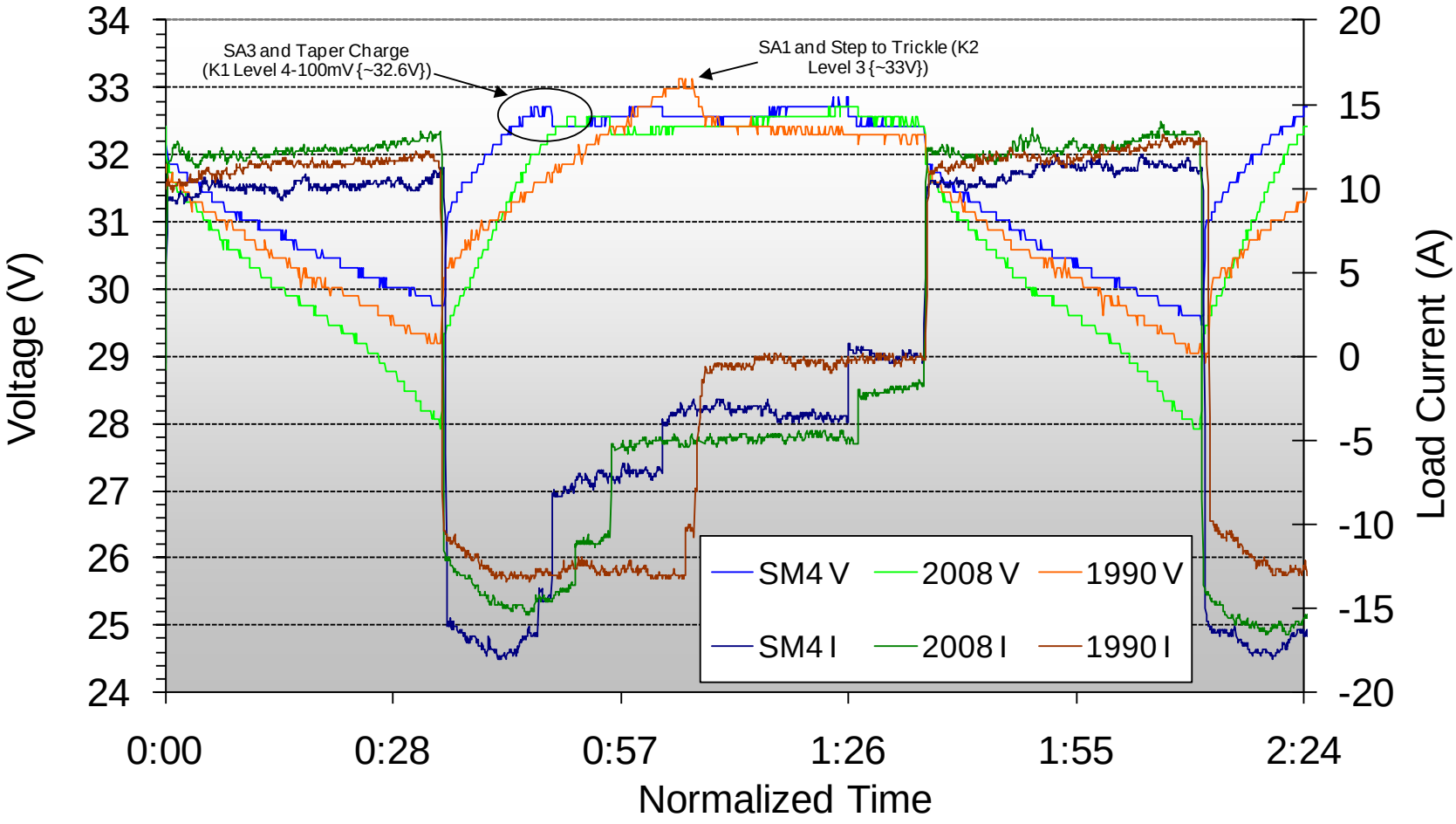


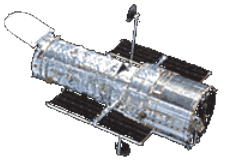
Battery Voltage Performance

- The 1990 Dry Sinter Voltage Profile Differs From The Other Profiles:
  - Software Step-to-trickle Charge Scheme Was Used vs. The Software Taper-charge Scheme
  - Less Powerful SA1 vs. SA3
  - Battery Temperatures:
    - 1990: ~ 0°C
    - 2008: ~ 0°C
    - 2009: ~ -2°C
- Orbit Day Duration Was Matched For All Profiles
- Battery Currents Were Approximately Matched (Within 2A Amps During Discharge) For All Profiles
- The Battery Voltage Profiles Indicate That The Replacement Batteries Maintain A Higher Voltage Throughout The Orbit Night Discharge Period Than The Original Batteries Had Just After HST Deploy Mission.
- The Plot Also Indicates The Degradation Of The Voltage Profile Between 1990 And 2008 For The Previous Batteries.
- At This Time, The On-Orbit Plateau Voltage Is Unknown And Can Only Be Determined By An Extended Discharge Period.

Battery Voltage Comparison

(Wet Slurry {SM4} vs Dry Sinter {1990 and 2008})



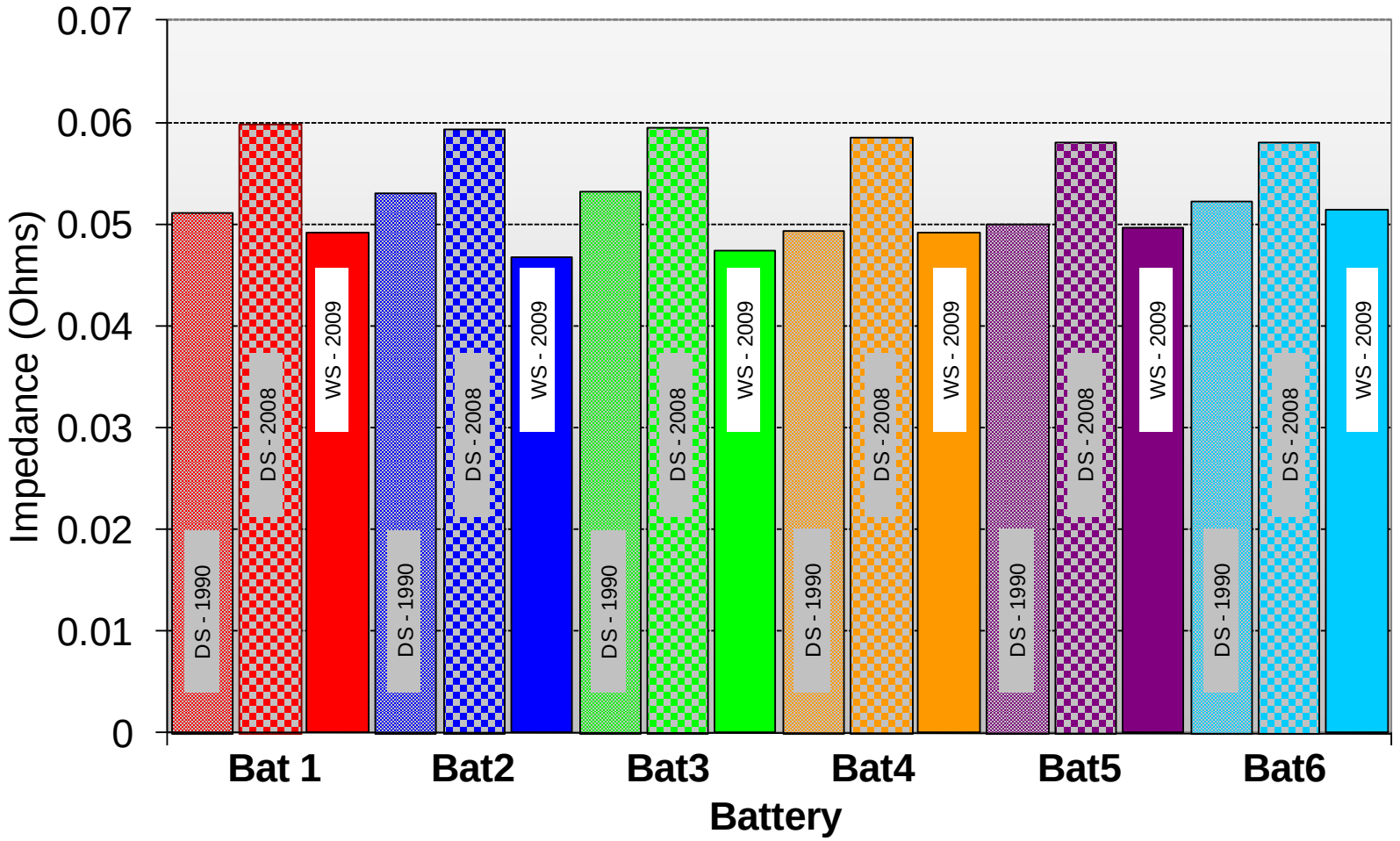


Battery Impedance

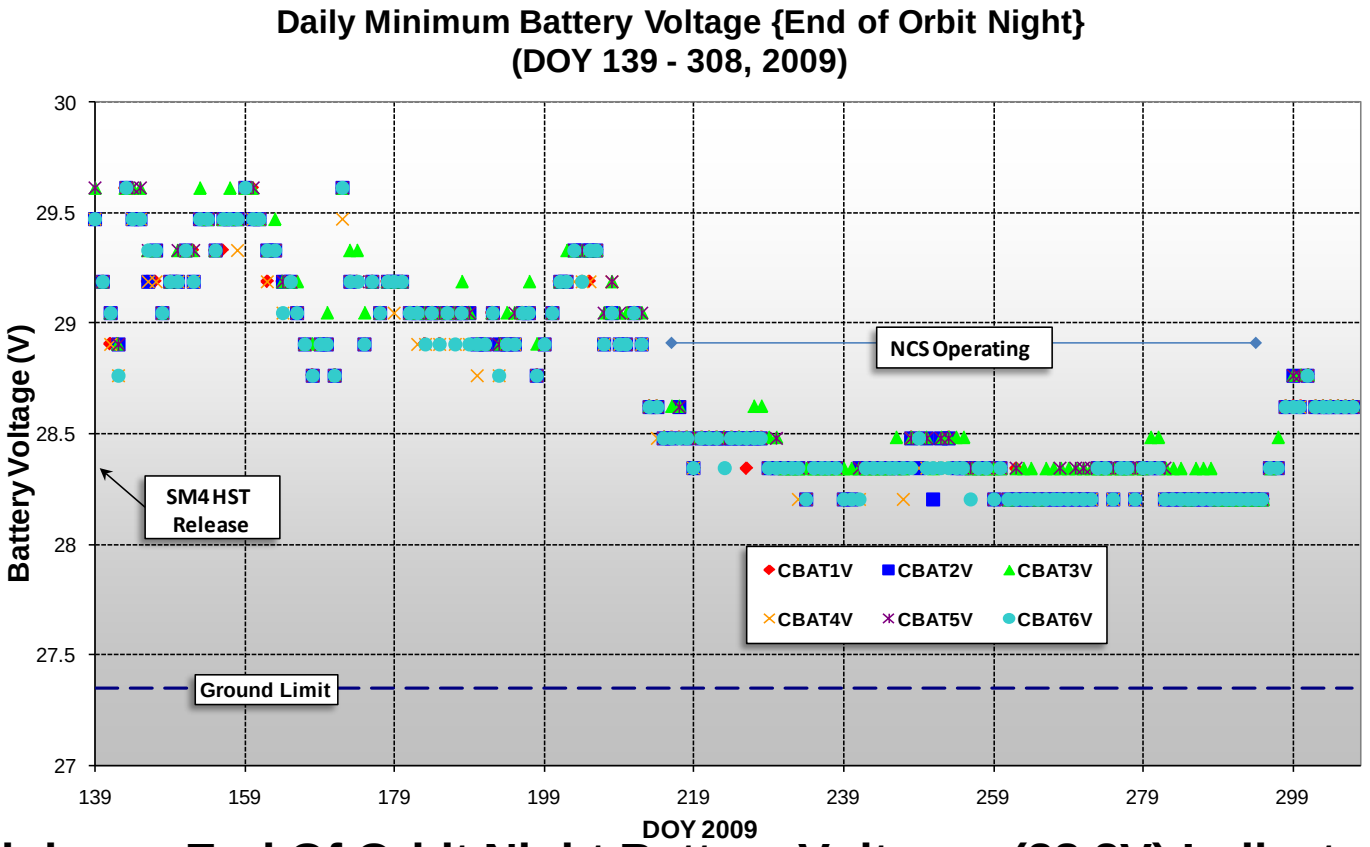
- The Battery Impedance Is Computed Using The Change In Battery Voltage Divided By The Change In Battery Current During The Night to Day Transition
- The Impedance Of The Replacement Batteries Exhibits Lower Impedance Than The Original Batteries At Beginning Of Life And After 18 Years On Orbit
- Impedance Includes 22 mohm Harness Resistance

Battery Impedance

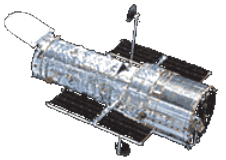
(Dry Sinter {1990 and 2008} and Wet Slurry {2009})



Minimum Voltage Performance



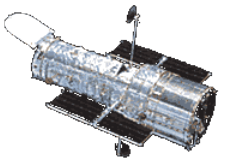
- **Minimum End Of Orbit Night Battery Voltages (28.2V) Indicate 0.85V Margin Vs. Ground System Limit Of 27.35v.**
- **When Compared To The Bus Voltage Limit Of 26.37V This And Accounting For The 0.8V Diode Drop There Is (28.2 – (26.37 + 0.8) = 1.03V Of Margin Vs. The Bus Voltage Ground Limit.**



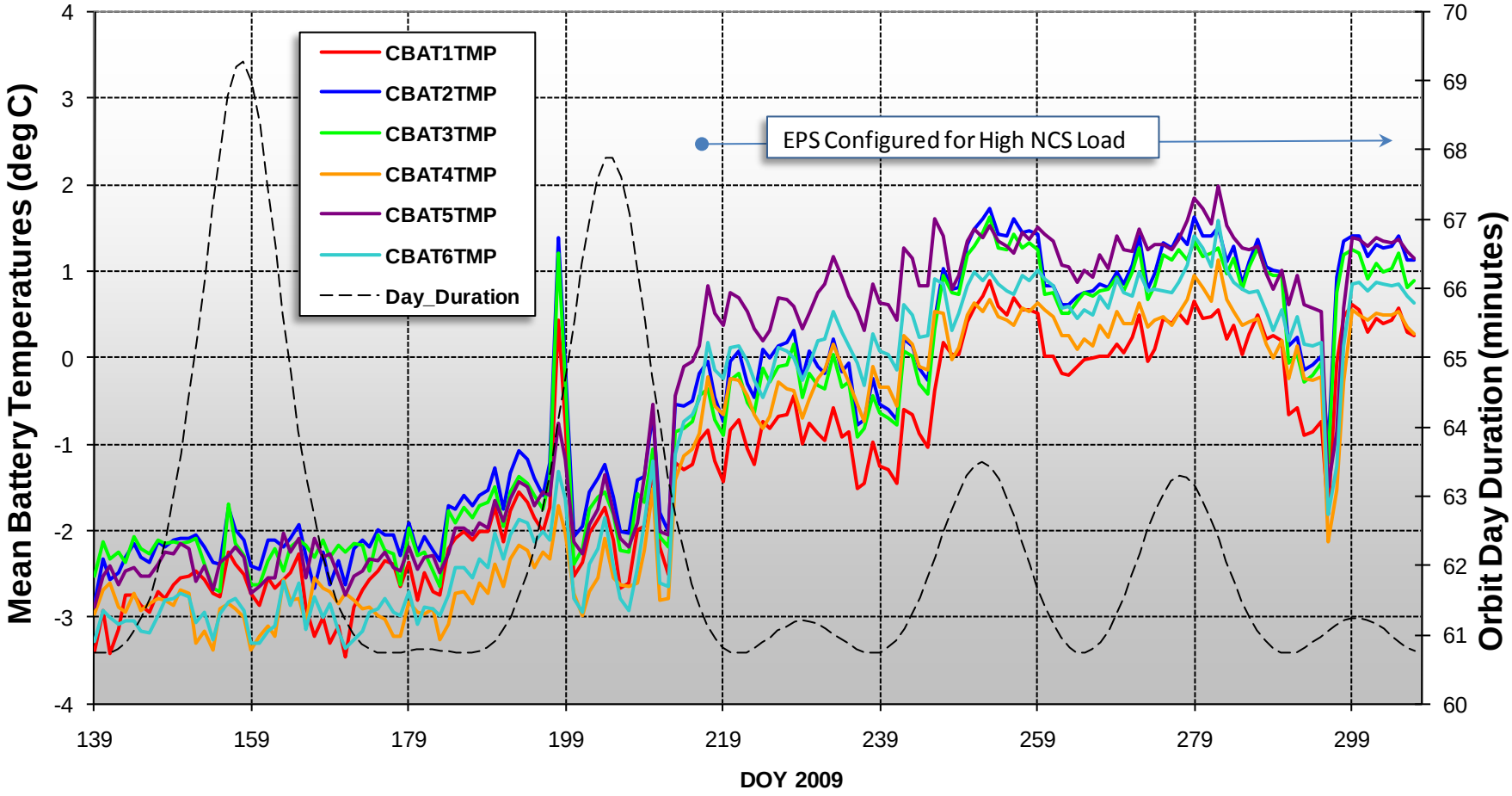
Battery Thermal Performance

- **The Battery Temperatures Range Between -5°C And -2°C With Excursions To 0°C, When The Redundant Heaters Activate in the Low Load Configuration.**
  - The Redundant Heaters Typically Cycle Between One And Two Times Within A 24 Hour Period
  - The Primary Heaters Remain Disabled To Allow The Batteries To Operate At Reduced Temperatures
- **In the High Load Configuration, The Daily Average Temperatures Range Between -1°C and 2°C**
- **HST Experienced Solar Beta Peaks On DOY 155 and 200 Which Resulted In A Peak Orbit Day Duration Of 69.3 Minutes and 67.9 Minutes**
  - Historically, The Batteries Have Tended To Heat-up During And/Or Following A Solar Beta Peak
  - No Heat-up Was Associated With These Events. The Lack Of Heat-up For This Recent Event May Be Attributed To The Good Condition Of The New Replacement Batteries And The Charge Control System Configuration
  - As The SOC Continues To Increase, The Batteries May Become More Sensitive To Such Beta Peaks

Battery Thermal Performance

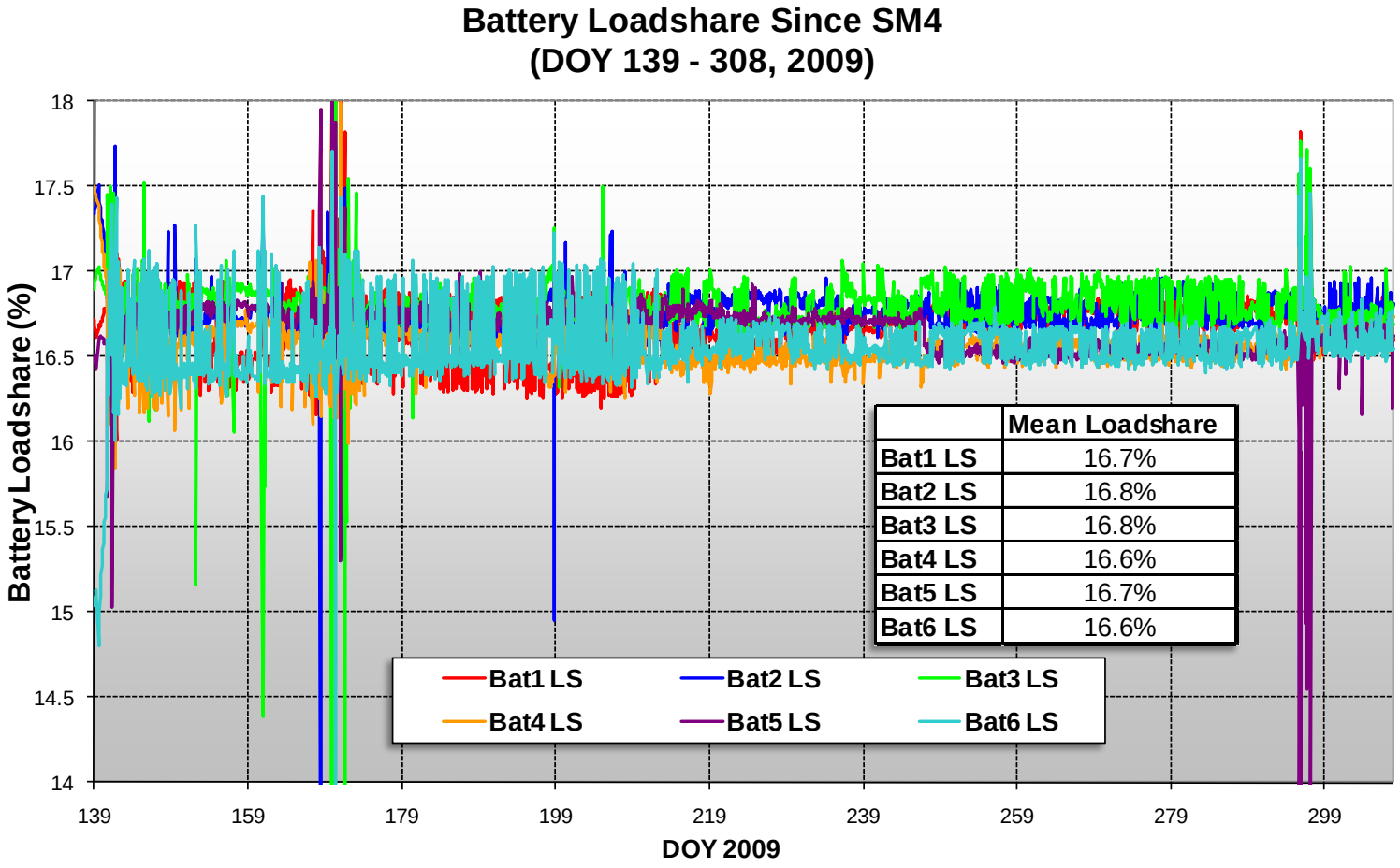


Battery Temperatures {Daily Mean}
Orbit Day Duration
(DOY 139 - 308, 2009)



Battery Current – Loadshare

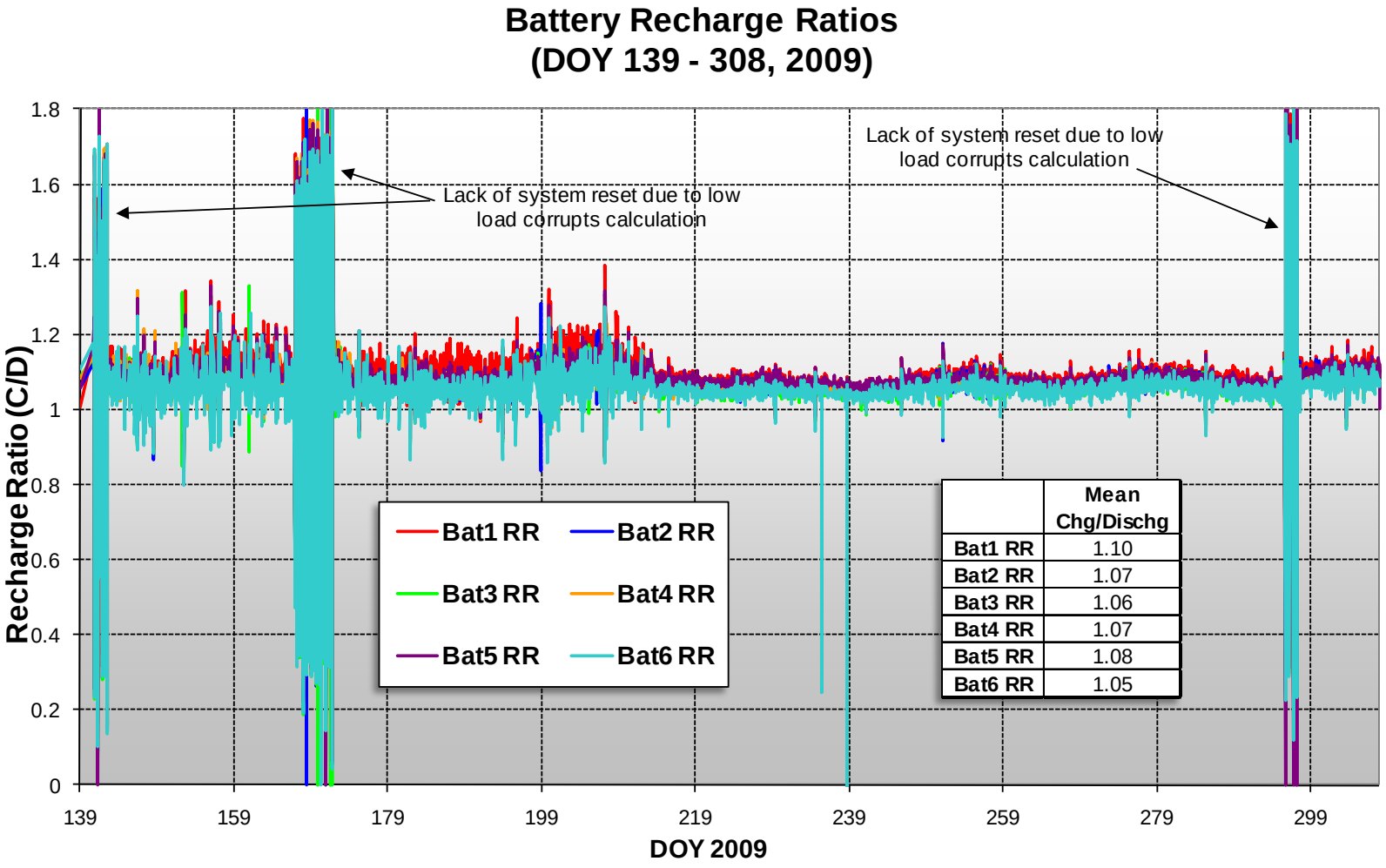
- **The Battery Load Share Is Well Balanced And Generally Within 16.2 To 17.2%.** (larger transients are due to low load condition)
  - Mean Load Share Deviation Among The Batteries Is 16.6 To 16.8%.



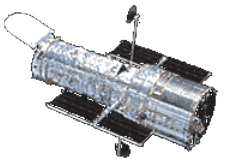
	Mean Loadshare
Bat1 LS	16.7%
Bat2 LS	16.8%
Bat3 LS	16.8%
Bat4 LS	16.6%
Bat5 LS	16.7%
Bat6 LS	16.6%

Battery System Recharge Ratio

- **The Mean Battery Recharge Ratios Range From 1.05 To 1.10.**



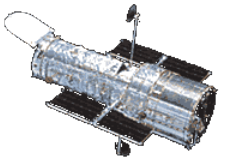
	Mean Chg/Dischg
Bat1 RR	1.10
Bat2 RR	1.07
Bat3 RR	1.06
Bat4 RR	1.07
Bat5 RR	1.08
Bat6 RR	1.05



Conclusion

- Replacement Batteries, Installed Into HST During Servicing Mission 4, Are Performing Well Within Specification.
- The Batteries SOC Provides Good Science Margin.
- The Voltage Performance Maintains The End User Equipment Well Within The Operational Input Voltage Specification.
- Voltage Performance Supported By Favorable Battery Impedance
- Charge System Providing Recharge Ratios That Maintain And Improve The Battery SOC While Maintaining Battery Temperatures Below 0°C
- Recharge Ratio And Temperatures Are Within Optimal Ranges

• The Batteries and the Charge System Are Healthy



ACKNOWLEDGEMENTS

- This Work Was Supported by NASA Contract Mod 593 Dated 2 June 1987
  - Directed LMSC to Design, Develop and Deliver Nickel-hydrogen Battery Modules
  - For the Hubble Space Telescope Low Earth Orbit Mission
    - Per NAS 8-32697 and NAS 5-5000.